Enabling Digital Air Traffic Controller Assistant through Human-Autonomy Teaming Design

Mohsan Jameel, Lukas Tyburzy, Ingrid Gerdes, Andreas Pick, Robert Hunger, Lothar Christoffels
Institute of Flight Guidance
German Aerospace Center (DLR)
Braunschweig 38108, Germany
Email: {mohsan.jameel,lukas.tyburzy,ingrid.gerdes,andreas.pick,robert.hunger,lothar.christoffels}@dlr.de

***Abstract*—The air traffic management domain has started to reap the benefits of Artificial Intelligence (AI) to support human controllers. However, the controller working position as the interface for managing air traffic is still limited to passively providing information, leaving the bulk of the tasks for human controllers, especially tasks involving decision-making. To meet the growing demands of air traffic, one way is to increase the level of automation in air traffic control systems. This requires a completely new task distribution for human controllers in combination with AI-based systems. Our paper will give an overview of our work related to the introduction of a digital Air Traffic Controller (ATCO) into an en-route controller working position. The digital ATCO is designed with the capabilities to perform several time-consuming tasks autonomously. The system is based on a meaningful distribution of tasks between a human and a digital ATCO. Several supporting tools and a Human-Autonomy Teaming (HAT) interface are described, which are able to handle different modes of HAT operations. Lastly, we describe a proof of concept setup of the system integrated in a controller working position that was presented at the AIRSPACE WORLD 2023.**

Keywords— Digital ATCO, Automation, Human-Autonomy Teaming, Air Traffic Control, artificial intelligence

I. INTRODUCTION

Over the last years exceeding advancement in AI techniques have been made which enables machines to perform exceptionally on complex tasks be it machine translation and language modelling or autonomous driving assistance systems. Meanwhile, the air traffic management domain has started to take the emerging possibilities of these techniques [1][2][3] into account. However, the controller working position as the interface for managing air traffic is still limited to passively providing information, leaving the bulk of the tasks for human controllers, especially tasks involving decision-making. Moreover, with the air traffic projected to increase substantially over the coming years [4] and new challenges related to improved ecological impact, the workload for human Air Traffic Controllers (ATCOs) will increase and severely restrict air space capacity [1]. Therefore, the level of automation in Air Traffic Control (ATC) systems needs to increase to meet the growing future demand, requiring a completely new task distribution for human controllers. Nevertheless, moving from the current to a highly automated system is a challenge, primarily due to the safety-critical nature of the operations. Taking these challenges into account, DLR started two projects; the DIAL project [6] (Der Individuelle und Automatisierte Luftverkehr-The individual and automated air traffic) and the LOKI project [7] (Kollaboration von Luftfahrt-Operateuren und KI Systemen - Collaboration of Aviation Operator and AI systems). DIAL focuses on implementing a stepwise approach for transitioning from current systems in use to a highly automated system of the future. Whereas, LOKI develops an interaction mechanism between humans and AI systems to address the acceptability, traceability, and predictability of these systems.

This paper presents the digital ATCO and the human-autonomy teaming (HAT) interface as two crucial components of a highly automated controller working position for en-route traffic. The first component is a digital ATCO, which we introduce as an integral element of a new controller working position (CWP) in combination with a single human ATCO and enhanced decision-support tools. The digital ATCO is designed with the capabilities to perform several time-consuming tasks, including conflict detection, conflict resolution, advisories, command creation and the ability to communicate with pilots using CPDLC. It allows the human ATCO to take on a more supervisory role. Furthermore, it will reduce the requirement of two human ATCOs to just one for managing en-route traffic. Each capability of the digital ATCO is developed as a service, which was initially developed as a supporting tool for humans. These services range from support for the development and application of conflict-free trajectories to the management of boundary handovers.

The system presented here is designed on the principle of service-oriented architecture, allowing different tools and functionalities to be developed and deployed as standalone services enabling seamless usage in more than one context. Atop these services, a data and service integration module is responsible for collecting data from different sources and providing the functionality of a service manager. In addition, the communication core enables interaction between services, a radar display, and a digital ATCO interface, which is responsible for the communication between digital and human ATCOs.

The second component of a highly automated controller working position presented here is the HAT interface design. HAT interface is the enabling component for a highly automated system as it provides interaction mechanics between human and AI systems. As safety-critical applications necessitate human oversight over AI systems, we present a HAT interface design that gives humans supervisory control over digital ATCO operations. Special consideration is given to keep the interface design as simple and intuitive as possible, with options to extend information on demand. Additionally, the digital ATCO uses attention guidance on special events to highlight affected flights, including the display of possible problems and solutions to keep the human ATCO in the loop. We provide three HAT control modes: human, hybrid and autonomous. In the human mode the human ATCO performs all traffic control tasks. The hybrid mode allows a human ATCO to transfer control of selected flights to the digital ATCO. The selection of the flights is left to the judgment of the human ATCO and his / her trust levels. Finally, the autonomy mode allows a complete control transfer to the digital ATCO, with human ATCO supervising all the operations. In all modes, the digital ATCO always informs the human ATCO of its actions.

Our paper will give an overview of the work related to the introduction of a digital ATCO. It is based on a meaningful distribution of tasks between a human and a digital ATCO presented in previous work [8]. Several supporting tools and a human-machine interface are described which are able to handle different modes of HAT. A proof of concept demonstrator of the proposed system with an adapted controller working position was presented at the AIRSPACE WORLD 2023 held in Geneva, showcasing the different operating modes [9].

II. Related Work

A. Automation in Controller Working Position

Automation has been a topic in ATC since decades not necessarily linked to the use of AI. We discuss tools and automation systems, which exist in the literature and how to enable different types of automation (autonomous) operation levels in CWPs).

HAAWAII [10], a SESAR funded project, focused on developing a speech recognition and understanding solution for automatic transcription of voice communication between pilots and ATCOs. It is developed with AI-based speech recognition models and aims to reduce controller manual documentation work. Another SESAR industrial research project, PJ33-W3 FALCO [11], aims to enhance the flexibility, cost-efficiency, and responsiveness of ATCO's to changing traffic demands. The target of this project is to develop operational procedures and tools to assist air traffic controllers in managing unfamiliar en-route sectors without local knowledge of traffic.

Figure 1 Main goals of air traffic control, sometimes called ATCO's mission

The MAHALO [12],[13] SESAR Exploratory Research Project investigated the question, if automation should be developed conformal or transparent to the human or even both. Regarding conformance, conflict detection supervised learning techniques and conflict resolution reinforced learning techniques were utilized to get an insight to human decision making in dynamic air traffic control tasks. As for transparency, the output of learning models had been made explainable by adopting the Ecological Interface Design framework, which served as a shared mental model between human and automated agents. The project provided findings and guidelines on how to incorporate conformance and transparent mechanisms of AI solutions to problem solving tasks in safety critical systems.

Talking about a digital ATCO as support and/or teammate for a single human ATCO, tasks needed to be defined and allocated comprehensively. Screening of meta research studies ([14],[15]) about ATCO tasks definitions showed a lack of a common agreed definition taxonomy. Nonetheless the main goal of ATC/ATM are typically stated as to provide safe, orderly and expeditious service (see Figure 1) [16]. Furthermore, high level tasks (groups) are often named the same or similar to *Separation*, *Monitoring*, *Coordination*, *Planning*, *Documentation* and *Communication* and if separated from the previous ones *Non-Nominal* (Emergencies, Abnormal or Unusual Situations) and *Ancillary Tasks* [8],[14].

B. Human-Autonomy Teaming Design

Since the introduction of machines, the question has arisen about the roles of humans and machines in the same working environment. Most importantly, it is challenging to define the role of higher automation and autonomous system, as autonomous systems exhibit capabilities of solving cognitive tasks. There has been debate in the literature about designing HAT focusing on the task and role distribution among humans and autonomy. An early effort was made by Fitts et al. [17] to categorize activities of air traffic control systems into human tasks and machine tasks. Their categorization was based on the principle "Men-Are-Better-At and Machines-Are-Better-At" in short MABA-MABA principle. The main shortcomings of the MABA-MABA principle originate from its rigid task distribution, where in reality, technology evolves and might render such a list outdated. Another popular framework is Level of Automation (LOA) which provides a taxonomy based on cognitive abilities. One such example includes four categories information acquisition, information analysis, decision making and action implementation. Similarly, LOA taxonomies are designed by various bodies like SESAR SJU [18] and EASA [19].

The nature of HAT is dynamic due to evolving nature of the technology and the personal human experience of working with the technology. In such cases, it develops technology centered around human and allows to delegate tasks from human control to autonomy when and where the human sees benefits, which is called the delegation of control principle [22],[23]. The delegation principle allows a flexible allocation of tasks to the system.

The success of a HAT is heavily dependent on efficient interface designs supported by appropriate levels of procedures and training. The efficient interface design focuses on the interactive part of the teaming, which allows humans to understand the working of autonomy and receive/give feedback about the task. Since the introduction of new automation will change the dynamics of the system, therefore, it should be supported by appropriate levels of training to enable humans to interact with autonomous systems, which focuses on pre and post teaming interaction. This paper focuses on the interactive part of the teaming design.

III. Digital Controller

Introducing higher automation in any system is an uphill task, especially in a safety critical environment. In our previous paper [8], we presented an automation concept based on three stages, each carefully designed to target various aspects of ATC operations. The three stages of highly automated systems are presented in Figure 2. The concept of "Single Controller Operations" (SCO) is the most significant contribution that will allow a single human ATCO to control en-route sector traffic. However, to enable SCO, it is necessary to support a human ATCO with a digital partner, which we called a digital ATCO, capable of performing various controlling tasks. The human ATCO can assign tasks to the digital ATCO based on its capabilities. The digital ATCO should have capabilities to assess the traffic situation, generate action plans and ability to implement those plans.

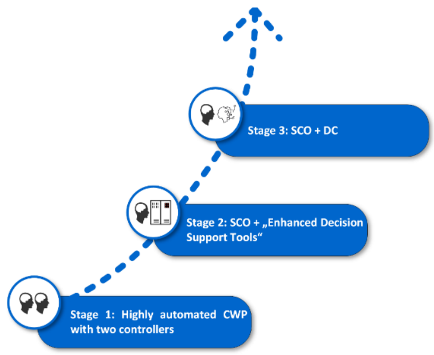

Figure 2: Stage wise approach to increase automation in the CWP. Stage 3 results in a fully develop Single Controller Operations (SCO) along with the initial integration of a digital ATCO (DC).

In this section, we present our digital ATCO, which is designed as an assistant to human ATCO. We provide a detailed overview of our design and implementation infrastructure to develop such a digital system. Our system provides a unified view of the traffic and other services developed to automate ATCO tasks, which allows human and digital ATCOs to have the same traffic picture and to develop action plans. This is a case of team situation awareness and one of the key factors for a successful team.

A high-level system architecture is presented in Figure 3. The main components of the systems are 1) CoDiST, a human ATCO radar display able to perform primary ATCO tasks, 2) DIRC, a digital interactive radar controller (a digital ATCO), 3) HI-DIRC, a HAT interface a communication medium between human and digital ATCO, 4) DASIM, a data and service integration module allowing seamless information retrieval and access, 5) various services and tools automating ATCO tasks. In the following subsections, we describe each component of the system in detail. The HAT interface (HI-DIRC) is explained in the next section.

A. Digital ATCO and DASIM service

A digital ATCO requires the same view of the traffic situation as a human ATCO and the ability to gather information from different supporting tools. It should be designed with a set of basic decision-making capabilities. For our approach, we developed amongst others services like a trajectory conflict checker, a trajectory generation and advisory tool. The latter considers a set of trajectories, detects conflicts and generates a conflict free trajectory as solution. Additionally, it generates the sequence of controller commands necessary to implement the trajectory. We also developed a boundary advisory tool that assists human to meet the boundary handover conditions and take necessary actions to disperse compact traffic situations efficiently. The communication between a human and a digital ATCO is mainly carried out using possibilities for information presentation already implemented into the special CWP designed for this project (III.B.1)) and an additional digital ATCO interface (IV.A). These services are described in the following section. The integration of all services as well as data integration and information presentation are carried out by a central tool called DASIM (Data and Service Integration Tool). This functionality enables the integration of all other tools into the ATC environment. Another important task for this tool is the analysis of the existing information for potential risks (e.g. conflicts between flights) and solving them by applying the connected services.

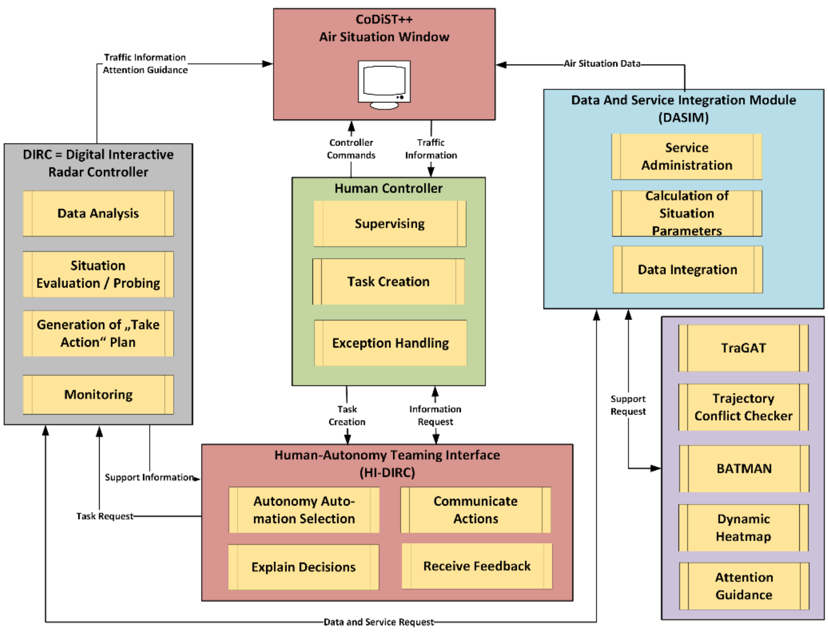

Figure 3: Overview of the System that enables a single human ATCO assisted by a digital ATCO

B. *Controller Display and Support Tools*

1) Controller Display and Simulation Tool (CoDiST):

CoDiST was implemented as (simulation) radar display for the upper airspace (Figure 4) and features typical functionalities found in corresponding tools used by European air traffic service providers.

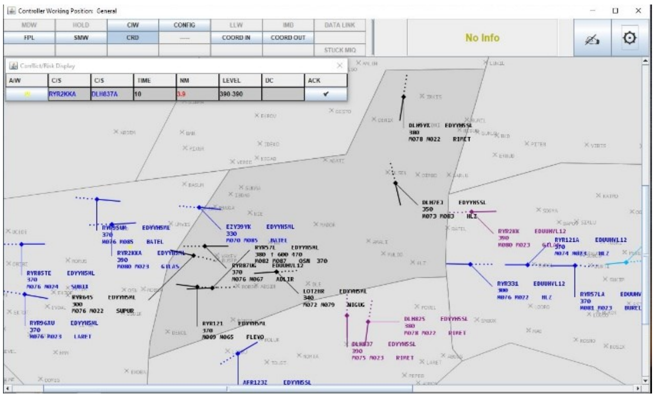

Figure 4 CoDiST Controller Display and Simulation Tool

Standard functions of controller displays like identifying and displaying conflicts in advance and offering support for the creation of new conflict-free trajectories by trajectory probing are implemented together with the possibility to display trail dots, a velocity vector, the complete flight plan or the trajectory in case of mouse-over a flight symbol. Customizing the display by selecting the visible level range, adding information or using a special color scheme are also possible.

Furthermore, it serves as a user interface for other tools which are connected to CoDiST using a RabbitMQ message broker. For external tools like DASIM (III.A) or BATMAN (III.B.4) the following functionalities for interacting with the controller display are possible:

- Paint additional information like colored sector boundaries or points of interest.
- Send controller commands like level or speed changes.
- Show information text below the selected flight label for a certain time.
- Mark flights in several ways (colored circle around position or boundary around label).
- Send heatmap data for a selected purpose (e.g. traffic density, ecological impact).

2) Trajectory Generation and Advisory Tool (TraGAT):

TraGAT is a separate service with the ability to create optimized trajectories. For the optimization process an evolutionary algorithm is used with a multi-objective evaluation function [20] consisting of a selected set of evaluation parameters which are listed in Figure 5. Avoiding conflicts with other flights, being in time, taking the flight parameter into account (route structure) and preferring short trajectories (length) are standards for optimizing trajectories, whilst sticking to the underlying route network or the original trajectory (route similarity) as far as possible and prefer directs to beacons (beacon preference) are more specialized.

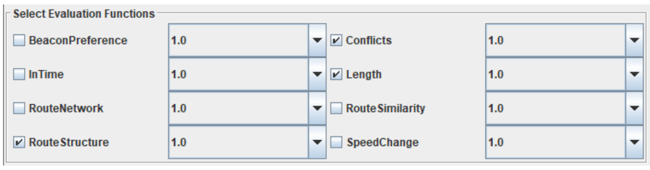

Figure 5: Possible evaluation functions for the optimization process.

The TraGAT service is activated by sending a trajectory request using the RabbitMQ message broker. The content of the message may vary with the selected set of evaluation parameters. In the example in Figure 5 neither the beacons nor the route network has to be included in the request. As result an optimized trajectory is sent back together with a list consisting of sets of commands and activation times to implement the suggested trajectory. This enables the receiving tool to handle the connection to the pilot automatically using text to speech or CPDLC.

3) Trajectory Conflict Checker (TCC):

Several services like TraGAT, BATMAN and DASIM as well need to check trajectories for conflicts on a regular basis. For this purpose, the TCC service was implemented and connected to the system environment using the RabbitMQ message broker. A TCC request consists of separation minima, the trajectory of the aircraft in question together with the trajectory of the possible conflicting flight and restricted areas. As result time, position and minimal distance between both flights are calculated together with begin and end time and position of the separation violation (see Figure 6).

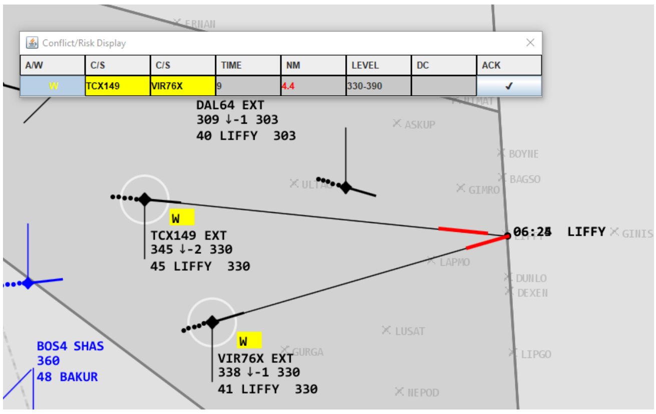

Figure 6: Presentation of the results of a TCC request in CoDiST (violation time as red lines, time and minimal distance shown in Conflict Risk Display)

4) Boundary Arrival Task Manager (BATMAN):

BATMAN provides information and advisories to fulfill the conditions to handover a flight to the next adjacent sector. Therefore, it can be used to endorse ATCOs to handle traffic in a less known airspace sector. It is attached to CoDiST and gets the planned trajectories from there. It shows the flights on a timeline regarding the planned handover times. Additionally, it calculates and provides speed advisories, can initiate automatic handovers and checks for possible conflicts when a flight level change is needed to fit the exit flight level.

The display (Figure 7) has the current time at the bottom, the flights stacked above, feature buttons and buttons to filter flights by the adjacent sectors. The label indicates the flight, if it is in the controlled sector, additional information and is linked to the time when the flight will reach the sector boundary. Each adjacent sector has its unique color to distinguish the traffic crossing different borders.

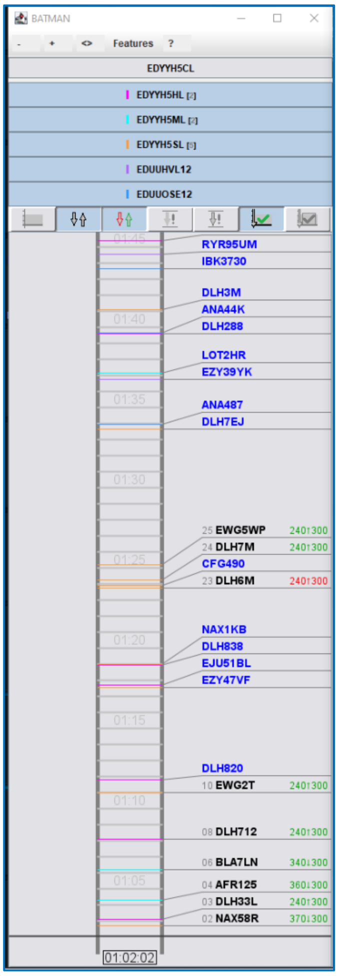

Figure 7: User interface of BATMAN

Several functions exist to provide information and advisories regarding handover conditions. BATMAN indicates if the exit flight level is not met already and if a change is possible without causing any conflicts.

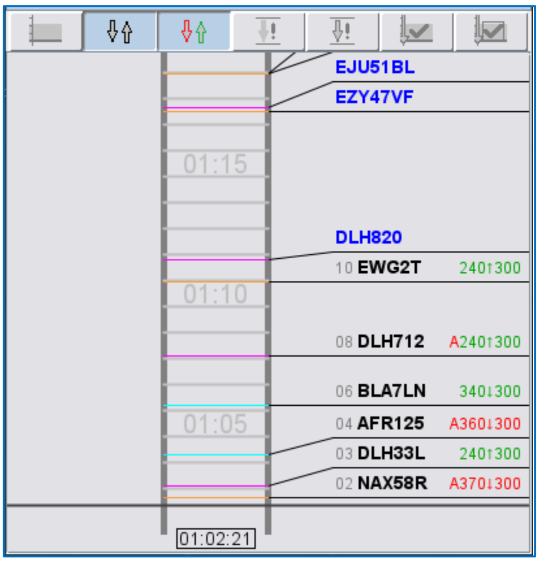

Figure 8: Indication of flight level change (current value, followed by a climb/sink indicator and the exit flight level) and if is conflict free (color coded)

Furthermore, BATMAN uses a minimum separation time between two aircraft entering an adjacent sector. If a flight is closer to its preceding flight, a speed advisory (always a decrease) is provided to maintain this time interval. The effect, if this advisory would be implemented, is shown with a second time on the timeline for the flight and all trailing flights, if they are also affected.

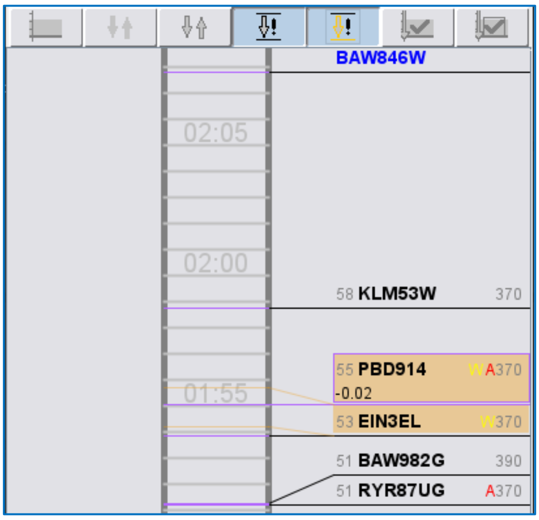

Figure 9: Indication of a speed advisory to maintain a given time interval between two flights when entering the next sector

5) Dynamic HeatMaps (DHMs):

Dynamic HeatMaps (DHMs) is an on-demand tool. Its primary purpose is to highlight the build-up of congestion or hotspots in the ATCO area of responsibility. To build a complete picture of future traffic, DHMs tool uses the flight plan information and forecast positions of the aircraft for a specified time horizon. This provides pointwise occupancy of the airspace. However, using only the pointwise information limits the visualization of the collective influence of aircraft occupancy in the vicinity. Therefore, we convert the pointwise information into density plots to capture the occupancy of the airspace by extrapolating pointwise information. The density plots allow to represent regions that are occupied by calculating the influence of nearby aircraft.

The density plots are visualized as color-coded heatmaps, where the high-intensity color represents high congestion or hotspot, and low-intensity colors represent open spaces. This tool is designed as an on-demand tool, meaning the ATCO can activate it when needed. The DHMs are created from up-to-date information about flight plans and flight trajectories. Figure 10 shows the activation menu integrated in CoDiST, whereas, Figure 11 and Figure 12 show instances of dynamic heatmaps created for 5 minutes and 10 minutes horizon. The color coding and horizon options are configurable, allowing it to be integrated with various radar displays.

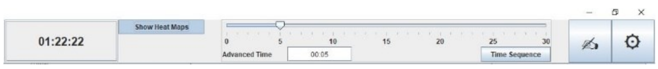

Figure 10: The menu of the Dynamic HeatMap tool with the option to activate and deactivate. The slider bar allows the selection of the time horizon.

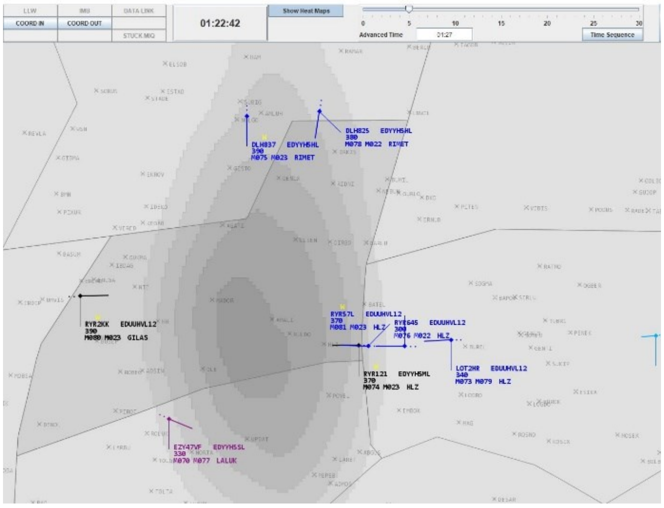

Figure 11 An instance of Dynamic Heatmap visualizing traffic densities for a 5-minute look-a-head window. The heatmaps are displayed as grey-scale values with darker intensities highlighting higher airspace occupancy.

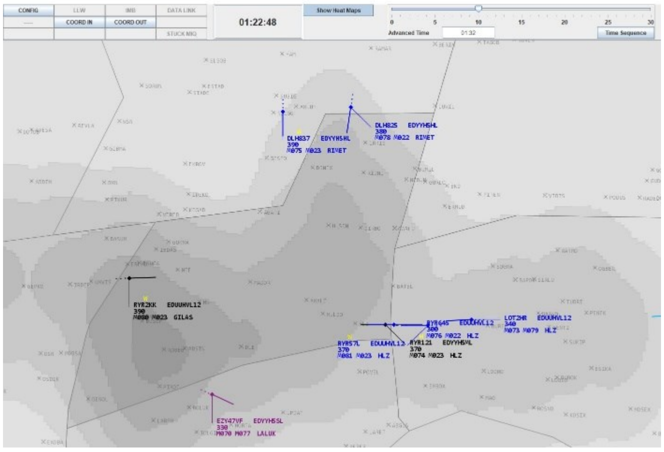

Figure 12 An instance of Dynamic Heatmap visualizing traffic densities for a 10-minute look-a-head window. The heatmaps are displayed as grey-scale values with darker intensities highlighting higher airspace occupancy.

6) *Attention Guidance (AG):*

Attention Guidance is a support tool that can highlight flight events on the radar display. The primary purpose is to notify ATCOs about important events needing immediate attention. AG is designed to provide three increasing levels of visual alerts. Level 1 is represented through a rectangular box around the flight label and is used for the lowest alert level. In Level 2, a filled circle without a border is added to the flight symbol, along with a rectangular box on the flight label representing the intermediate level. Level 3 is the highest level of AG, and it is represented through a filled circle with a border and a rectangular box on the flight label. The level change is sequential and varies with the intensity of the event.

For example, if there is a conflict between two aircraft where the time to conflict is less than five minutes, Level 1 is activated on both aircraft labels. The AG will be activated for 10 seconds at an interval of 30 seconds. Once the time to conflict drops to less than three minutes, Level 2 is activated for 10 seconds with 30 seconds intervals. Once the time drops below one minute, Level 3 is activated. If ATCO chooses to solve the conflict at any time between the activation of the AG, the AG is disabled on the resolved conflict between a pair of aircraft.

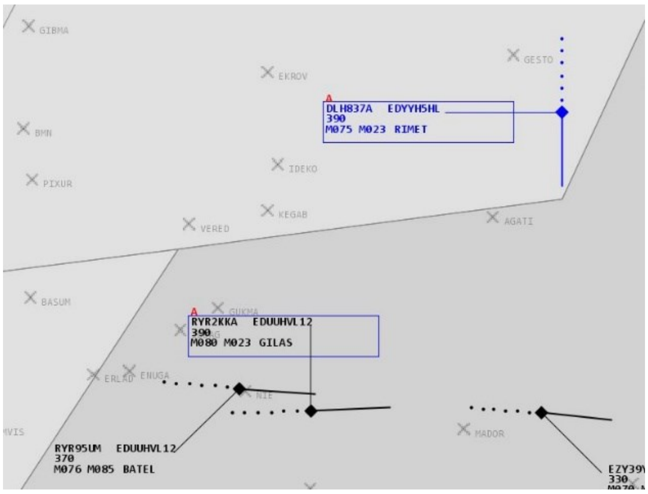

Figure 13 Attention Guidance Level 1 activated for the event conflict between two aircraft.

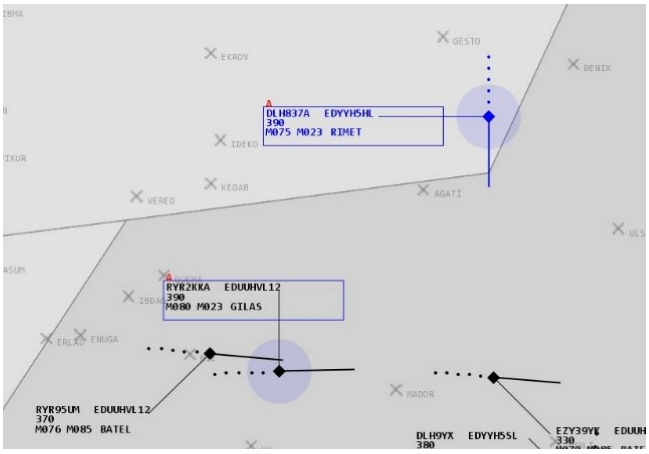

Figure 14 Attention Guidance Level 2 activated for the event conflict between two aircraft.

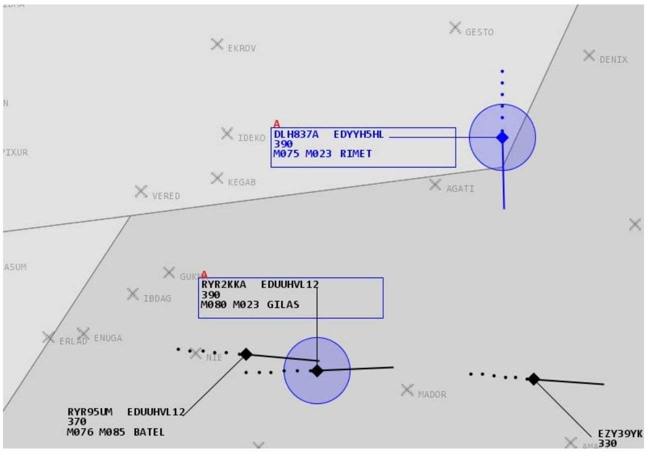

Figure 15 Attention Guidance Level 3 activated for the event conflict between two aircraft.

IV. Human-Autonomy Teaming Interface

In this section, we discuss how HAT is integrated as the second component of a highly automated controller working position. In particular, we present a HAT interface design that is developed as an interaction mechanism between human and digital ATCO.

A. Digital Controller Interface Design

With the integration of a digital ATCO in the CWP, the need arises to provide the ATCO with the possibility to interact with the digital ATCO. Such interactions are the activation and deactivation of the digital ATCO, as well as the delegation of control for specific aircraft to the digital ATCO or vice versa. At the same time, the human ATCO needs to be informed of the actions carried out by the digital ATCO at all times to keep a high level of situational awareness of the traffic situation in the sector.

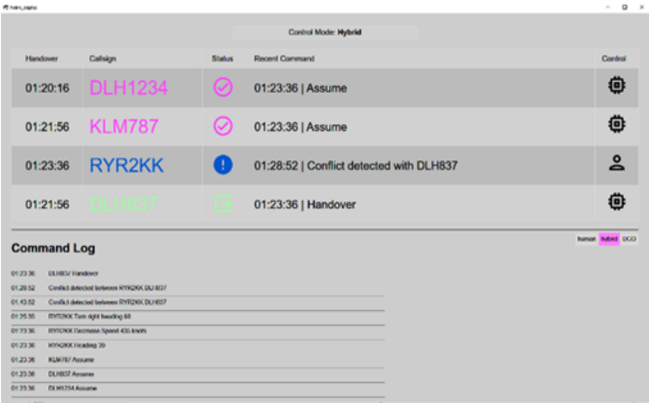

Figure 16 Screenshot of the HI-DIRC display

The decision was made to keep this information and control separate from the air situation display CoDiST, to prevent information cluttering. Instead, the HI-DIRC was implemented on a second display to the right of the main air situation display.

The design of HI-DIRC comprises three different areas with information about each currently active flight: the *strips* with most basic flight information, the *command log* and the *autonomy mode status and selector*.

1) HI-DIRC strips

The information panel layout design in HI-DIRC is inspired by electronic flight strips [21] that are commonly used in different CWPs. Each active flight has a corresponding strip that contains all current information regarding status, most recent command and control mode, as shown in Figure 17.

Figure 17 The flight strips in HI-DIRC give an overview of the current status of each flight, the most recent command or status update received by the flight, as well as the current control mode (human or digital ATCO)

By default, the strips are sorted in dependence of the calculated handover time to the next sector, based on the trajectories provided by DASIM. Both status and callsign of each flight are also highlighted in the same color-scheme as the CoDiST. Additionally, the most recent command given to the aircraft is displayed in the column *Recent Command*. Here, the digital ATCO can also display status updates to flights, for example by notifying the human ATCO that a solution for conflicting aircraft has been found, before executing the command.

The last column of the flight strips displays the control status of the flight. In the current iteration, a flight is either under control of the human or digital ATCO.

2) Command Log

The Command Log (see Figure 18) contains a log of all commands that have been issued by the digital ATCO to aircraft delegated to it as well as status reports with timestamps. This enables the human ATCO to retrace the history of actions of the digital ATCO at any time, even for past periods and aircraft that are no longer in the sector.

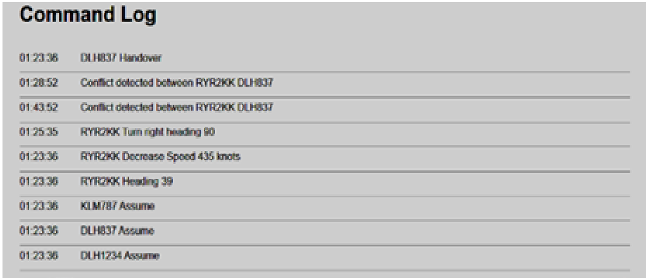

Figure 18 The Command Log in the HI-DIRC display serves as a history of all commands and status updates of the digital ATCO

3) HAT Mode Status and Selection

The HAT mode selector in the bottom right of the display gives the human ATCO the option to switch between the different autonomy modes. The currently active autonomy mode is also highlighted at the very top of the display. The purpose of the three different autonomy modes is described in the following section.

B. Human-Autonomy Teaming Modes

For the initial version of the integration of the digital ATCO into the CWP, three different autonomy modes have been implemented. The autonomy modes give the human ATCO a quick access to decide the level of autonomy of the system and can be changed on the HI-DIRC display at any time. The autonomy modes available to the human ATCO are Human, Full Autonomy, and Hybrid, which is collaborative variant of the previous both.

1) Human Mode

The *Human* mode gives the human ATCO full control over every aircraft within the area of responsibility. In this mode, the digital ATCO is essentially deactivated, as previously delegated aircraft are delegated back to the human ATCO. This mode is basically the same as the current mode of operation of the human ATCO, but with support of advanced tools.

2) Full Autonomy Mode

The mode *Full Autonomy* delegates the control of all tasks to the digital ATCO. In this mode, the human ATCO is merely monitoring the actions of the digital ATCO and is free to handle other tasks (e.g. coordination, pre-planning). This mode is primarily intended for periods with low traffic or traffic that require no or just minimal interaction due to a low degree of complexity.

3) *Hybrid Mode*

The autonomy mode *Hybrid* is intended as the default control mode and is the basis for the concept of HAT for en-route control. In this mode, the human ATCO has the option to delegate individual aircraft to the digital ATCO at any time, as well as to reassume control of individual aircraft that have previously been delegated to the digital ATCO. Thereby, the human ATCO can choose which tasks the digital ATCO should handle primarily.

If this mode is active, every new active flight is under manual control by default. But the human ATCO can use the *Control* column in the HI-DIRC display to delegate an aircraft to the digital ATCO by clicking on the corresponding symbol, as well as taking a previously delegated aircraft back under his control.

V. Design Verification of digital ATCO

To verify the feasibility of a digital ATCO system and the interaction of the different tools, a proof of concept CWP was developed and presented at the Airspace World 2023 in Geneva, pictured in Figure 19.

Figure 19: Proof of concept demonstrator presented at "Airspace World 2023" in Geneva with CoDiST on the central display. BATMAN and HAT interface are located on the right display.

The proof of concept setup integrated all the tools described in this paper. The center display contained the radar display, which acts as a primary interface to the human controller, and a digital ATCO capable of handling traffic controller tasks, including generating action plans and implementing them. Some basic capabilities include assume and handover flights, conflict detection and resolution, and communicating commands through CPDLC. The right display contained the BATMAN and HI-DIRC HAT interface. The traffic scenario simulated real traffic and consisted of an en-route sector over the German airspace. A human ATCO interacting with the system was able to select a mode among human, hybrid and full autonomy.

The digital ATCO concept was appreciated by the participants of the trade show. In particular, there were various valuable discussions with the ANSPs, ATCO and industrial partners. ATCOs were especially interested in providing their inputs in the design improvement and validation phases of the projects.

VI. Future Work

In this paper two crucial components of a highly automated controller working position for en-route traffic were discussed. It was outlined that for the processed use case of a digital ATCO working together with a human ATCO the task allocation needs to be defined. This reflects back to the question of defining ATCO tasks. A brief literature review showed that there is no common agreed ATCO task definition, therefore a new model [8] was build up using inputs from task definitions from the literature. The first component, the digital ATCO, was described as an overlaying system able to use former ATCO support tools in the same way as a human ATCO. A number of such tools, implemented as services, were explained. The second component, the HAT interface design, was presented and its components and their scope were illustrated.

Based on the proof of concept demonstrator presented at Airspace World 2023 Geneva, the next step is to build up a prototype of the digital ATCO. Therefore, the ATCO task definition has to be reworked, as to including AI aspects as well as arising new ATCO tasks from HAT. The second step is to decide on tasks to allocate to the digital ATCO on a theoretical design level based on an assessment of highest benefit. In parallel, the herein described tools will be evaluated in terms of feasibility, utility and usability for SCO in a Human-in-the-loop simulation campaign involving human ATCOs. As possibly every ATCO (sub)task can occur in a variety of situations making the (sub)task itself more or less effortful for an (human or digital) ATCO to execute, another step is required to learn about the limitations of the digital ATCO. As there will be at least some of them, it is also important to define a redelegation process back to human control, which is not yet implemented in the demonstrator. Most importantly, after this first verification of the HAT interface including the design, the autonomy modes and general concept of communication and information exchange process between human and digital ATCO, we need to validate the setup in Human-in-the-loop simulations.

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